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INVESTIGATION AND IMPROVEMENT OF THE RELIABILITY OF THE C-141A --ETC(U)

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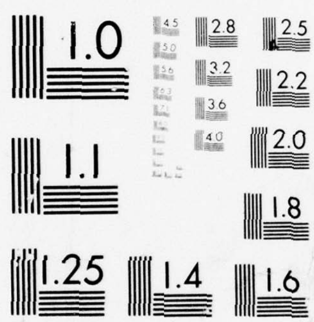

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FINAL REPORT

INVESTIGATION AND IMPROVEMENT OF THE RELIABILITY OF THE C-141A AIRCRAFT MASTER CAUTION CONTROL UNIT

See back page for 1473

JULY 1976

Prepared for
PRAM PROGRAM OFFICE
SAN ANTONIO AIR LOGISTICS CENTER
KELLY AIR FORCE BASE, TEXAS
under Contract F09603-76-A-3231-SA02

ARINC RESEARCH CORPORATION

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Prepared for

PRAM Program Office
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by

D. Dahl

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FOREWORD

The work reported on herein was performed under Air Force Contract F09603-76-A-3231-SA02, issued on 17 March 1976 by the Directorate of Procurement and Production, San Antonio Air Logistics Center, Kelly Air Force Base, Texas. The program was conducted under the technical direction of Mr. H.H. Stein, MM (1)/PRAM Program Office, SA-ALC.

Flight test of modified units was supported by the 438th Military Airlift Wing, McGuire Air Force Base, under the direction of Mr. T. Sheveha. The aircraft measurements made at Warner Robins Air Force Base were supported and coordinated by Mr. R. Skelton and Mr. J. Settles.

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ABSTRACT

This report presents the results of a program to improve the reliability of the C-141A Master Caution Control Unit, NSN 6340-00-918-8427. The program was performed by ARINC Research Corporation under contract with the PRAM Program Office, San Antonio Air Logistics Center, Kelly Air Force Base, Texas, during the period 17 March 1976 through 21 July 1976.

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SUMMARY

A four-man-month program of measurement and circuit analysis was performed to identify and recommend design changes that would improve the reliability of the C-141A Master Caution Control Unit (MCCU) and the interface with the associated aircraft Caution Indicator System. On the basis of field and laboratory measurements, it was determined that destructive transients existed under certain operating conditions. These transients were found to cause failures of the MCCU transistors.

A modification was developed to add transient-suppression diodes to the MCCU on the three significant system interface lines. This modification is recommended as the least expensive and most effective method for preventing transient damage. It is also recommended that, for the present design, commercial transistors be more carefully screened to reduce quality defects.

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CONTENTS

CHAPTER ONE

INTRODUCTION

This Final Engineering Report describes an ARINC Research Corporation effort to investigate and improve the reliability of the C-141 Master Caution Unit, NSN 6340-00-918-8427. The four-man-month program was performed under Air Force Contract F09603-76-A-3231-SA02 for the PRAM Program Office, San Antonio Air Logistics Center.

1.1 SCOPE OF WORK

In accordance with the contract statement of work, ARINC Research conducted a program to identify and recommend reliability improvements to the C-141A Master Caution Control Unit (MCCU). The program included measurements of aircraft power characteristics, controlled laboratory tests, circuit and component analyses, development of modifications, and delivery of modified units to McGuire Air Force Base for flight testing.

1.2 ENGINEERING APPROACH

The first steps in the program described herein were to obtain the required government-furnished equipment (GFE) and technical documents and develop an appropriate project plan. An interim report, which included the related Project Plan and Schedule, was submitted on 12 April 1976. The C-141A Aircraft Power Measurement Test Plan was submitted on 15 April 1976. These activities were followed by measurements on the C-141A aircraft, design and construction of the laboratory test fixture, execution of the laboratory tests, failure-mode and component analysis, and development of the required modifications.

A shortage of serviceable units in the Air Force supply system made it difficult to obtain the required operable or repairable GFE. The Master Caution Control Unit is normally scrapped when repairs cannot be performed at the base level. The first four units received for this program were scrapped units; considerable repair time and a number of special components were required to restore them to operable condition. Delays were also encountered in procuring the replacement components. Two new units were received late in the program, as were seven additional scrapped units (only two were repairable). The problems with scrapped units delayed the flight

testing and resulted in one unrelated failure once the tests had begun. This unrelated failure was analyzed in the context of the circuit and component analyses and is also discussed in this report.

The measurements on the aircraft were made during one trip to the C-141A overhaul depot at Robins Air Force Base and one trip to an operating wing at McGuire Air Force Base. For these measurements a test box (including a Master Caution Control Unit) instrumented with appropriate test points was fabricated so that aircraft measurements could be made without disrupting the existing aircraft wiring.

A laboratory test fixture was also designed and built in order to duplicate the interfaces with the other aircraft caution system elements. This fixture permitted simulating power and signal transients and examining thermal characteristics.

The failure mode and component analysis included verification of component stress levels, review of applicable specifications, examination of failed components, microscopic examination of failed transistors, detailed test of new and failed transistors, and simulation of the observed transistor failure modes.

After the primary factors in MCCU failures were identified, appropriate modifications were incorporated and tested.

1.3 ORGANIZATION OF REPORT

This final report summarizes the results of the study and corrective actions recommended for improving the reliability of the C-141A Aircraft Master Caution Control Unit. Chapter Two is a description of the system and installation, and Chapter Three provides details of the problem investigation. Chapter Four is a discussion of the development and testing of the recommended modifications. Conclusions and recommendations are presented in Chapter Five.

CHAPTER TWO

SYSTEM INSTALLATION AND OPERATION

2.1 SYSTEM DESCRIPTION

The Master Caution System in the C-141A aircraft is designed to monitor the status of 50 systems or functions critical to aircraft and crew safety. At present, 46 of the available circuits are being utilized, leaving four spare channels for future use.

The C-141A Master Caution System comprises the following major components:

- Master Caution Light and Combination Clear Switch -- one for pilot and one for copilot
- Master Caution Control Unit -- one per aircraft
- Annunciator Panel Assembly consisting of 50 display lights
- Annunciator and caution light test switch -- one per aircraft
- Fault-sensing switches located at monitoring points throughout the aircraft

The Master Caution Control Unit was the focal point of this investigation. Figure 2-1 is a block diagram of the Master Caution Warning and Control System.

2.2 AIRCRAFT INSTALLATION

Figure 2-2 illustrates the installation of the caution system components in the C-141A aircraft. The Master Caution Control Unit (MCCU) is mounted under the pilot's control console on the left forward side. The two master caution light reset switches are mounted on the instrument panel directly in front of the pilot and copilot. The annunciator and caution light test switch is mounted on the right side of the control console, just below the annunciator display panel. The annunciator display panel, with its warning lights for the 50 individually monitored functions, is mounted on the forward edge of the control console.

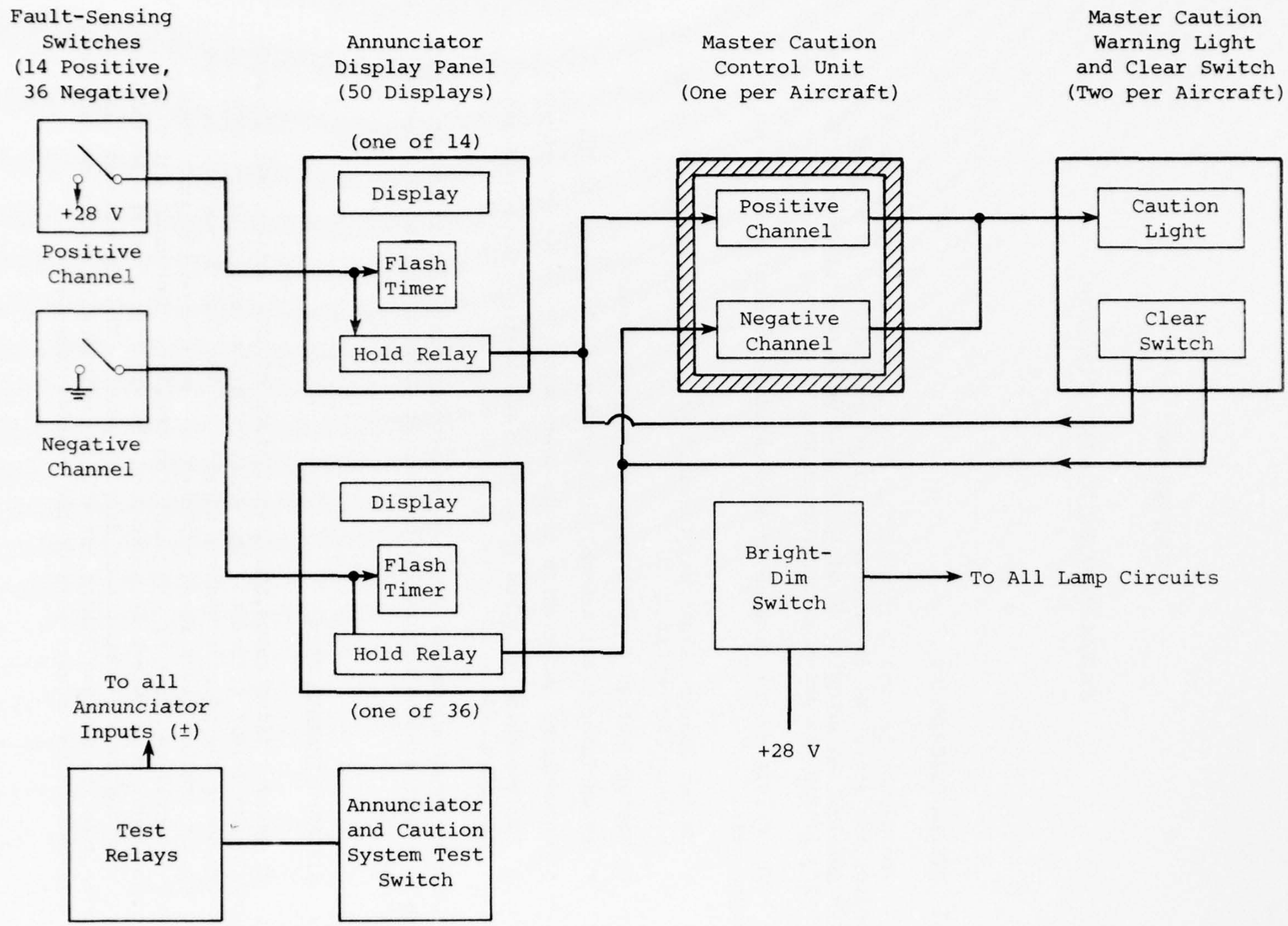


Figure 2-1. BLOCK DIAGRAM, MASTER CAUTION WARNING AND CONTROL SYSTEM

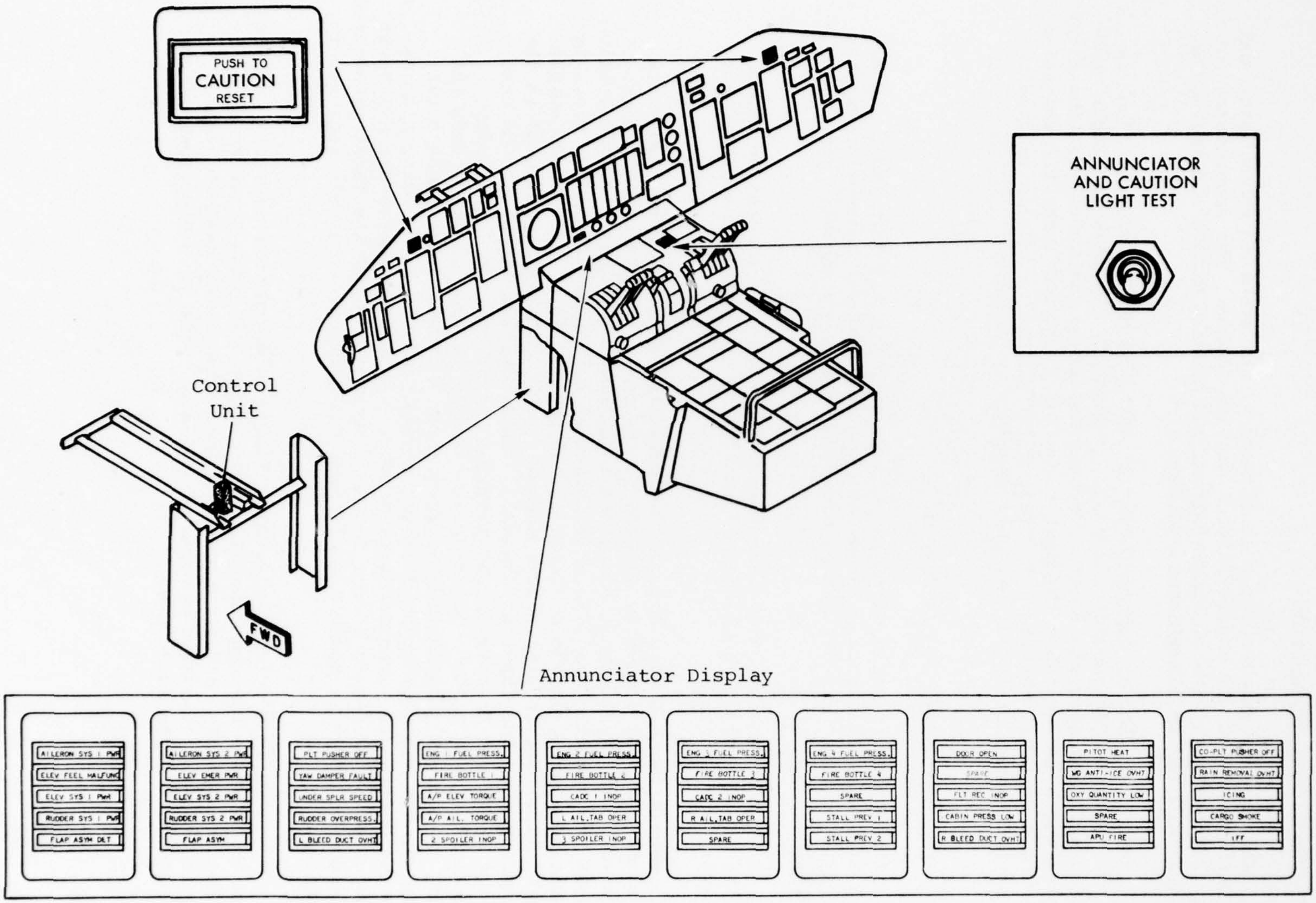


Figure 2-2. INSTALLATION OF CAUTION WARNING SYSTEM COMPONENTS

2.3 FUNCTIONAL DESCRIPTION

When a fault occurs, it is indicated by the specific annunciator and by both the pilot and copilot master caution lights. The annunciator display flashes at a rate of approximately 100 times a minute and the master caution display is illuminated continuously.

When the pilot or copilot observes that the master caution light is on, he looks to the annunciator panel to identify the flashing light associated with the specific fault. He then depresses the master caution light reset, which extinguishes the master caution light and locks the annunciator light on until the fault is cleared (or aircraft power is removed). If an additional fault occurs, this sequence is repeated.

2.4 ELECTRICAL CIRCUIT DESCRIPTION

The system is designed to respond to either a +28 volt fault signal or a ground fault signal. In applicable Air Force maintenance documents, the fault signals are defined as positive (+28 V) or negative (ground) functions.

A brief description of the circuit functions for a positive channel follows. (The negative channel is similar except that it has reversed-polarity components.)

When a fault occurs and the fault-sensing switch closes, +28 volts from the isolated dc bus is applied to the specific annunciator input. This +28 volt input signal energizes a unijunction transistor timer, which causes the specific annunciator to flash at a rate of 100 to 175 times per minute, depending on the position of the panel light's brightness switch. The fault signal is also routed through the holding-relay solenoid in the annunciator to the input of the MCCU. This positive signal to the base of the 2N719 NPN transistor actuates the master caution light relay, illuminating the pilot's and copilot's master caution lights. When the pilot or copilot presses the master caution indicator, the light extinguishes, the annunciator hold relay latches, and the annunciator display becomes continuous. The annunciator will remain illuminated and all fault indications will remain stored in the annunciator until the fault is cleared or aircraft power is removed. If a new fault occurs, the same sequence is repeated.

The MCCU is a relatively simple design using two transistors: an NPN type 2N719 and a PNP type 2N3063. Two reed relays, each actuated by one of the transistors, are provided to control the master caution lights. Figure 2-3 is a schematic diagram of the unit. The MCCU uses power from the +28 volt isolated dc bus.

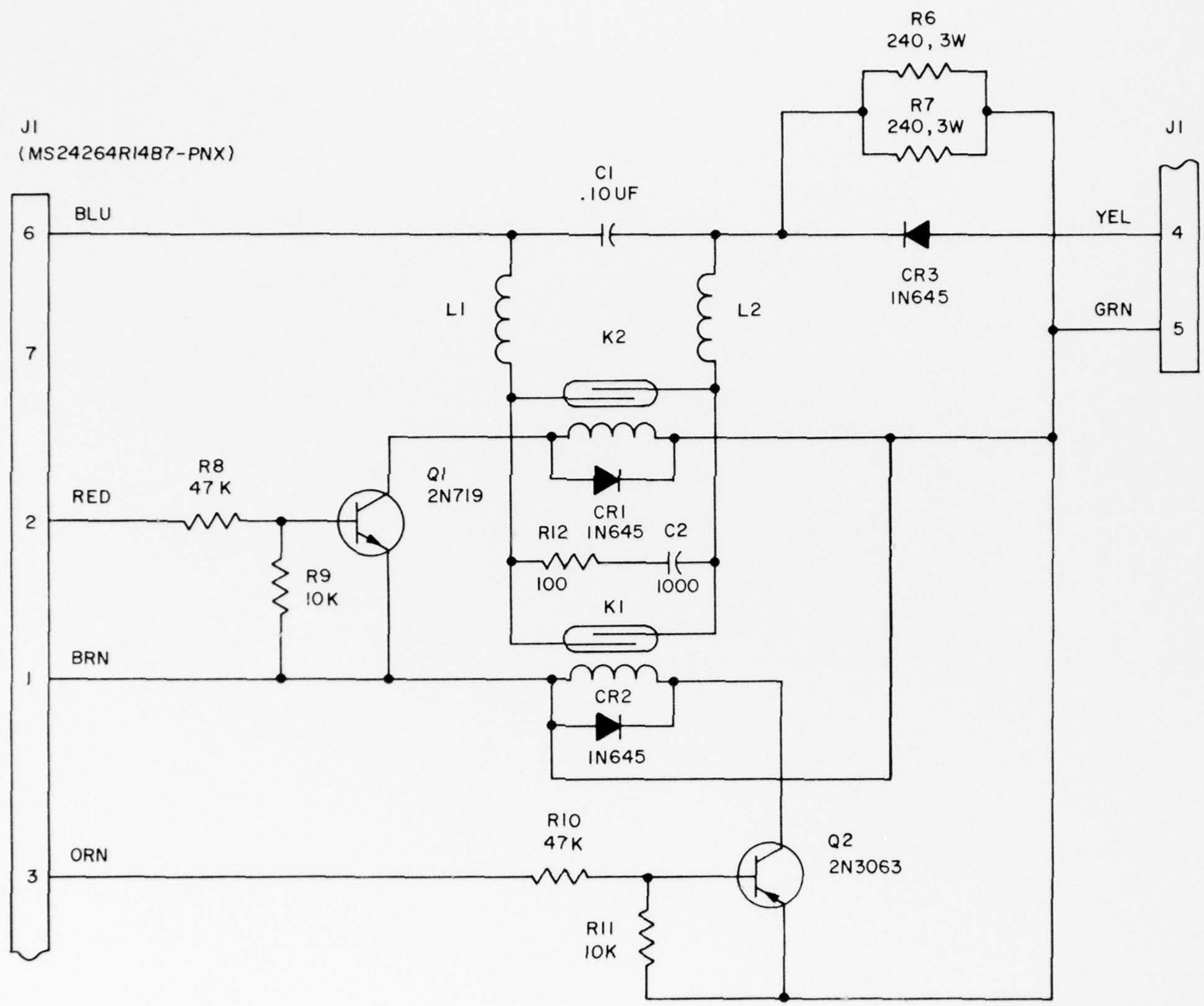


Figure 2-3. MCCU SCHEMATIC DIAGRAM

CHAPTER THREE

ENGINEERING ANALYSIS AND PROBLEM IDENTIFICATION

3.1 PROGRAM PLAN

To determine the reason for the unacceptably high number of replacements of the MCCU, ARINC Research conducted a program that included measurements of the aircraft interfaces supplemented by laboratory tests and analysis.

We performed the initial aircraft measurements on two aircraft at Robins Air Force Base to identify transient characteristics associated with the aircraft power bus at the MCCU input.

We then designed a laboratory test fixture in order to duplicate the interfaces with the aircraft system. This fixture permitted continuous electrical cycling, simulating the annunciator operation of the caution control system. Line transient and thermal conditions were simulated, and measurements were performed.

To explore further some of the laboratory findings, we performed additional measurements on C-141A aircraft at McGuire Air Force Base, using battery-powered test equipment so that aircraft power could be monitored during power application and removal.

Failed transistors were analyzed for more accurate identification of the electrical and physical failure mechanisms.

The results of the problem-identification process, including aircraft measurements, laboratory tests, circuit analysis, and transistor failure analysis, are presented in the following sections.

3.2 AIRCRAFT MEASUREMENTS

The primary purpose of the initial measurements was to identify possible anomalies in the C-141A aircraft power applied to the Master Caution Control Unit (MCCU). The measurement requirements were established on the basis of a review of the circuit description in applicable Air Force technical documents.

For this effort, we built a special test fixture (see Figure 3-1) designed to plug into the aircraft MCCU connector. With this fixture, it was possible to monitor all input lines to the MCCU, as well as the collector and base terminals of both transistors in the unit. Utilizing aircraft power, we made aircraft measurements with a dual-trace portable storage oscilloscope (Tektronix Type 466) in conjunction with the test fixture.

These tests, made on two aircraft at Robins Air Force Base, had the primary purpose of identifying possible operating transients on the +28 volt power applied to the caution control system. We exercised several aircraft systems to determine if transients occurred on various aircraft power modes. These tests did not identify significant transients on the +28 volt bus. On one aircraft the MCCU was found to have a defective positive channel. The positive channel would stay keyed continuously once it received a fault input and would not clear. The negative channel was normal. The C-141A maintenance technicians reported that this was the predominant problem with the MCCU. In laboratory tests that followed, we determined this type of failure to be the result of collector-base or collector-emitter leakage in Q1, the 2N719 transistor. The laboratory investigation into the factors producing this type of failure indicated that an undetected transient was occurring.

On the basis of the laboratory tests, we visited McGuire Air Force Base on 14 June 1976 to perform additional C-141A aircraft transient measurements. On this second field trip, in addition to the ARINC Research test fixture and the type 466 oscilloscope, we utilized positive- and negative-peak detector test boxes supplied by the San Antonio Air Logistics Center PRAM Office. We adjusted the two test boxes to sample peak levels of 50, 80, 200, and 400 volts. During this test, all test equipment was operated from independent battery power to assure that transients that could have been missed in the first set of measurements could now be identified.

The aircraft made available for testing was C-141A S/N 8076, which had a history of MCCU failures, including five failures during the period 6 April through 14 June 1976. With the battery-powered oscilloscope, it was possible to observe conditions during aircraft power application and removal without imposing interruptions in the oscilloscope supply that could inhibit observations.

We used the oscilloscope to monitor the +28 volt input line to the MCCU, and the positive- and negative-peak detector units to monitor the signal input lines.

The peak detectors recorded both positive and negative transient spikes with amplitude between 200 volts and 400 volts at the input to the positive channel of the MCCU. These peaks occurred when the caution control reset switch was actuated the first time to clear the flashing annunciator displays, following the application of aircraft power.

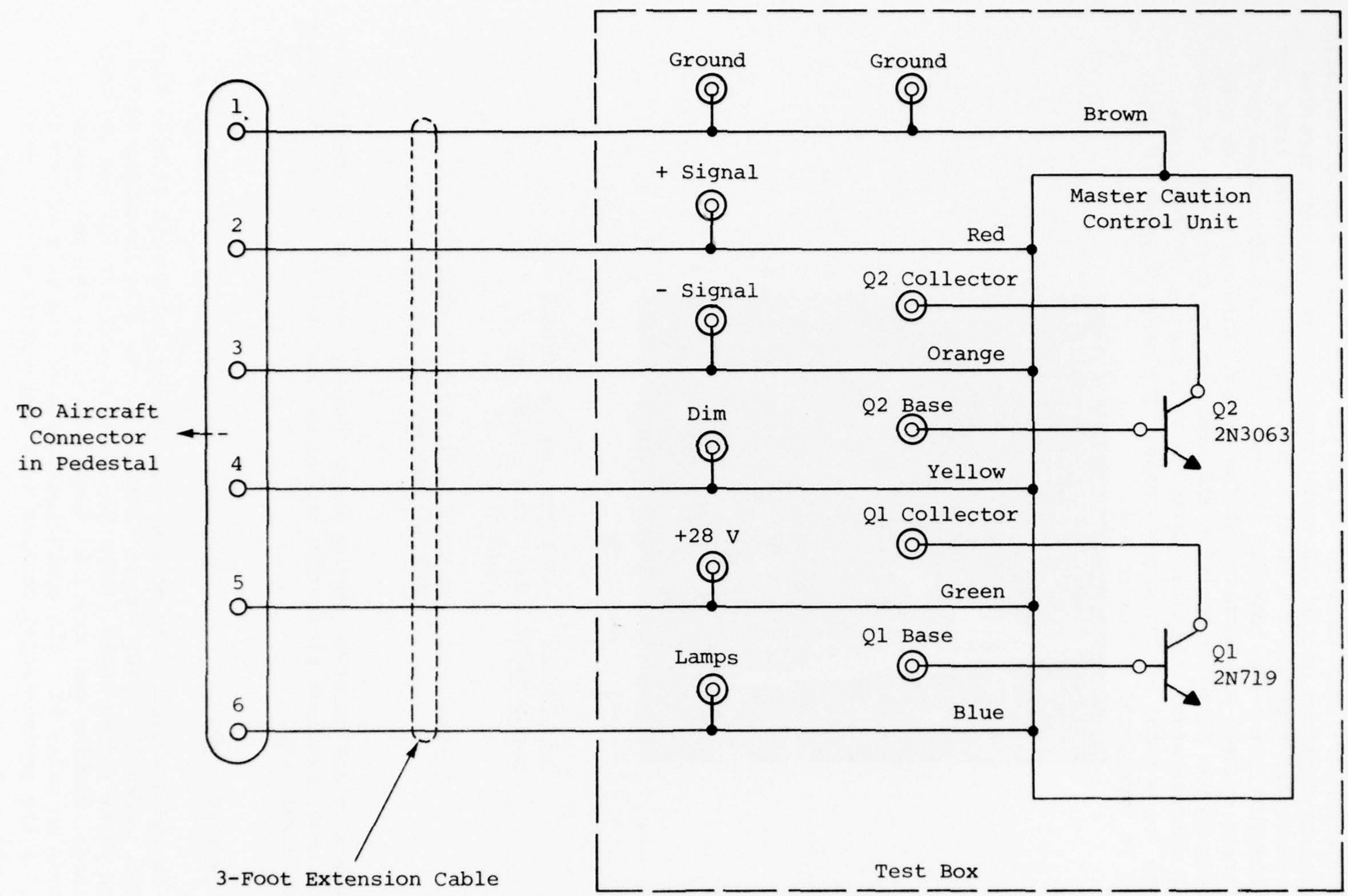
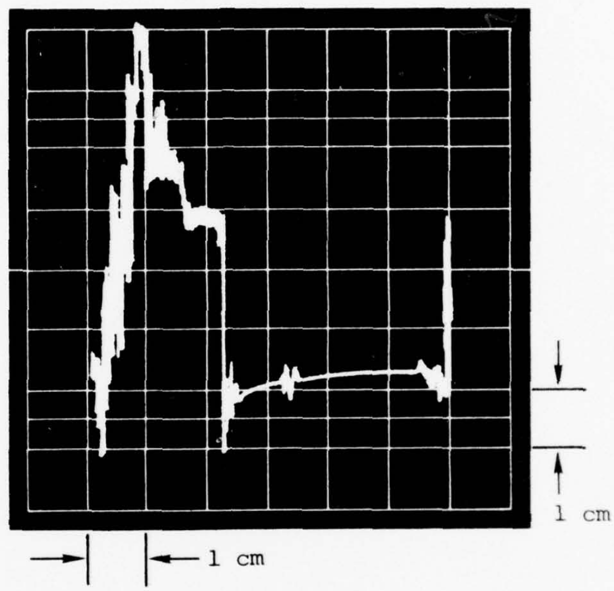


Figure 3-1. SPECIAL TEST FIXTURE FOR AIRCRAFT MEASUREMENT

Transients were also observed on the +28 volt line. The most significant transient waveform on the +28 volt input line to the unit appeared when the annunciator displays were flashing, the master caution light was on, and aircraft power was suddenly removed. This condition could occur when aircraft systems are actuated during ground maintenance. The peak level observed was 80 volts positive and negative for durations of approximately 50 microseconds. This was followed by a series of lower-level transients for a total of 200 microseconds. The scope display of this condition is reproduced in Figure 3-2.



Amplitude: 20 volts per centimeter
Sweep Speed: 50 microseconds per centimeter

Figure 3-2. +28 VOLT INPUT LINE TO MASTER CAUTION CONTROL UNIT (MCCU)

The conditions observed during these tests at McGuire Air Force Base indicated that transient protection should be provided for the signal lines and the +28 volt bus.

3.3 LABORATORY TESTS

We designed a laboratory mock-up to simulate the C-141A caution warning system, including power supply transients. We also instrumented the MCCU with three thermocouple probes to record transistor (Q1 and Q3) body temperatures, dimming resistor (R6) temperature, and internal ambient temperature on relay K2. The operational test of the unit was conducted, in part, in the environmental chamber at a temperature of 85°C (see Section 3.6).

Figure 3-3 is a block diagram of the laboratory mock-up for testing the MCCU. The laboratory test fixture was programmed for the following events:

- Fault signal
  - Annunciator light on, flashing
  - MCCU on
  - Master caution light on
- Clear master caution light
  - Master caution light off
  - Annunciator light on, steady
- Clear fault
  - Annunciator light off

These events were generated during a 1.6-second interval and were repeated after 1.2 seconds of dead time.

To assess the interface with the aircraft system, which has 14 positive and 36 negative fault-indicating channels, we simulated one each of the positive and negative annunciator channels in the laboratory tests.

The scope display reproduced in Figure 3-4 shows the waveforms recorded at pin 2 and pin 5 of the MCCU under test in the laboratory mock-up. The sweep speed was 0.5 second per cm and the amplitude was 100 volts power cm. The upper waveform is at the positive input (pin 2) of the unit. This duplicates the aircraft conditions, showing the +28 volt fault signal and the transient of approximately 300 volts that appears when the master caution light is pressed to clear.

The lower waveform shows the power supply transients simulated at the +28 volt power input terminal (pin 5) of the MCCU. The simulated transients are approximately 1.5-second bursts of 10-millisecond spike duration. The peak levels of the spikes are approximately +240 volts and -30 volts.

All MCCUs received for this study were operated in the laboratory mock-up both before and after modification. We subjected one unmodified unit to 24 hours' repetitive cycling at 85°C in the environmental chamber with a power-supply input voltage of 34 volts, representing the most severe set of conditions. No failures of any type were induced by the extreme test conditions.

Analysis of the aircraft configuration shows that a severe transient condition will occur when aircraft power is applied, actuating several

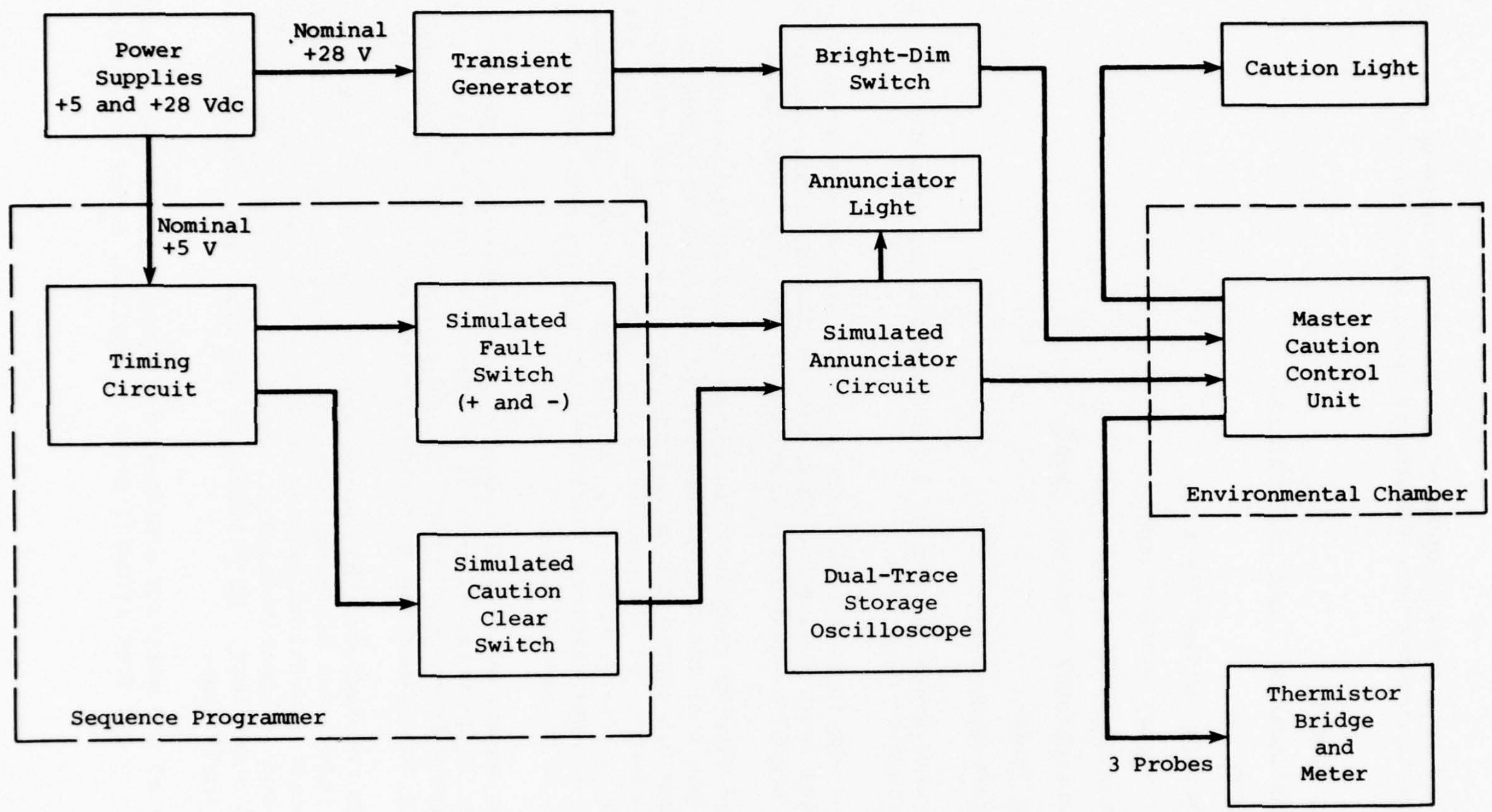
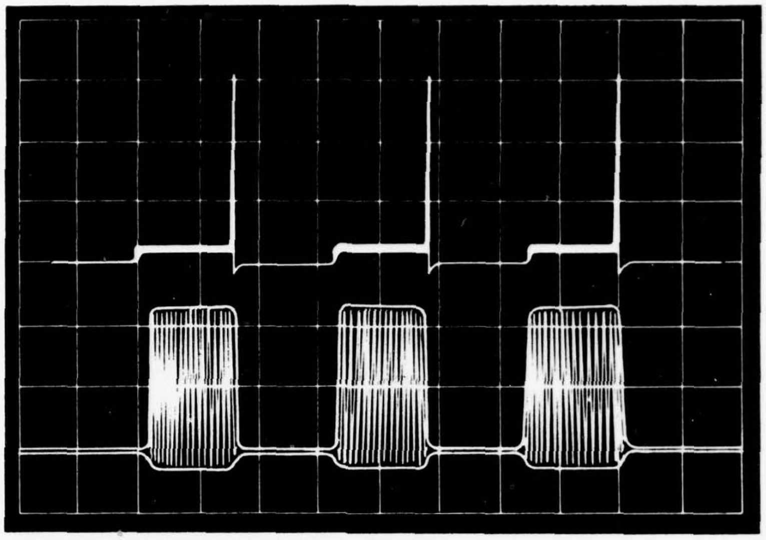


Figure 3-3. LABORATORY MOCK-UP, C-141A CAUTION WARNING SYSTEM



Amplitude:	100 volts per centimeter
Sweep Speed:	5 seconds per centimeter
Upper:	MCCU Pin 2 - positive-signal input terminal
Lower:	MCCU Pin 5 - +28 volt input terminal

Figure 3-4. LABORATORY MOCK-UP TEST WAVEFORMS

annunciators, and then removed without clearing the master caution control lights. At the time power is removed, the inductive transient from the annunciator holding relays is present at the input to the MCCU. The transient levels and duration for this release of multiple annunciator relays cannot be reliably predicted, since individual transients are combined to cause the overall transient. They were observed on the aircraft to be higher in some instances than the transients developed during laboratory testing. They also vary from aircraft to aircraft, as well as from occurrence to occurrence, depending on aircraft wiring variations and the number and position of annunciators activated. The laboratory tests permitted the selection of transient-protection components that can adequately suppress all observed transients with a substantial safety margin.

The laboratory tests confirmed that no significant transient levels were generated by the internal relays in the MCCU since suppression diodes have been included in the design.

Research into available transient-suppression devices identified the type 1N5555 as an ideal device for the MCCU application. Laboratory tests of units with the type 1N5555s selected for application demonstrated that transients at all levels and durations were limited to a safe peak amplitude of about 34 volts. The type 1N5555 functions as a normal diode for opposite-polarity pulses, which limits these pulses to about 0.6 volt.

The manufacturer reports the response time of the 1N5555 transient-suppression diode to be better than 1×10^{-12} seconds. The forward-surge rating is 200 amperes for 1/120 second at 25°C. The 1N5555 transient-suppression diode is qualified to MIL-S-19500/434.

Incorporation of three transient-protection diodes in the one MCCU is a more economically feasible solution to the problem than modification of the 50 annunciator circuits.

3.4 CIRCUIT ANALYSIS

The MCCU includes two switching transistors and two reed relays to control power to the master caution light. To facilitate operation on a +28 volt input signal or a ground input signal, one transistor is an NPN device (2N719) and the other a PNP device (2N3063). A schematic diagram of the unmodified MCCU was shown in Chapter Two.

To describe the operation of the MCCU circuit, it is necessary to consider other parts of the warning system, such as the annunciator and controls.

Figure 3-5 is a simplified diagram of the positive channel. RFI filters and dimming circuits have been deleted for clarity, and only one channel is shown. (The negative channel functions in essentially the same way except for its reversed polarities and the use of a 2N3063 PNP transistor in the MCCU.) The functions of the various circuit elements are described in the following paragraphs.

When a fault is present, the fault switch or relay closes, applying +28 volts to the annunciator input. The annunciator display flashes at a rate of approximately 100 times per minute. This +28 volt fault signal is also routed through diode D1, relay K1, and diode D3 to the input of the MCCU. This +28 volt signal is divided by resistors R1 and R2 and applied as forward bias to the base of Q1, the 2N719 transistor. With Q1 foward-biased, K2 energizes and supplies +28 volts (less in the "dim" mode) to the pilot and copilot master caution light displays (two identical, parallel displays).

To clear the master caution display, the pilot or copilot "clear" switch is energized. This grounds the input to the MCCU and also energizes K1. When K1 is energized, it latches and switches the annunciator from a flashing to a steady display, removing the +28 volt input signal to the MCCU. Transistor Q1 turns off, relay K2 deenergizes, and the MCCU is then free to respond to a new annunciator (fault) signal. Diode D4, which is connected across relay solenoid K2, provides transient protection for Q1 at turn-off. There are 14 positive annunciator channels connected in parallel to the MCCU (there are also 36 negative channels).

The annunciator and caution-light test switch actuates relays that simultaneously energize all annunciator caution lights.

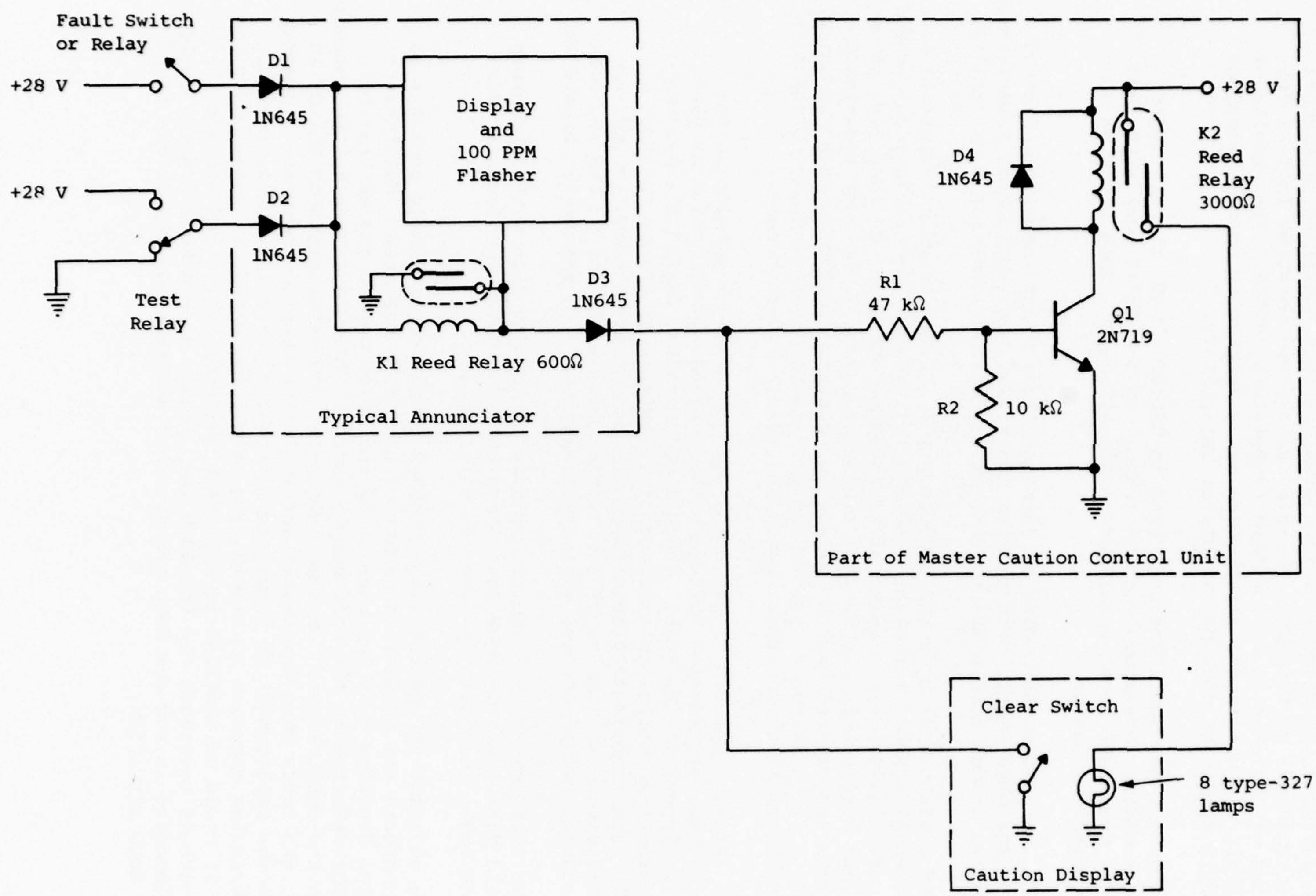


Figure 3-5. POSITIVE CHANNEL, CAUTION WARNING SYSTEM

We measured and calculated the normal circuit operating parameters for both channels of the MCCU. We also considered derating factors for operation of the unit at an elevated temperature (85°C). The results of this effort did not reveal any problem areas related to normal deratings that would appear to degrade transistor reliability.

If we assume conditions as stated in MIL-STD-704B, the specified collector-emitter breakdown voltage (BV_{CER}) of the 2N719 equals the +80 volt peak transient level specified in MIL-STD-704B. This would be considered marginal design.

After analyzing the MCCU, we examined the complete caution indicator system. The most significant problem identified was the lack of transient-suppression diodes across the holding relays in the annunciator assemblies.

The present design of the MCCU does not include transient protection from external sources for either the +28 volt power line or the input signal lines. Virtually every element of the system containing an inductive component and a switch is a potential transient source. The most troublesome transients are created by the collapsing magnetic field of a relay inductor when its current is suddenly interrupted. Factors contributing to transient generation are switch contact bounce and relay contact bounce.

In laboratory tests of circuits, using conditions simulating the C-141A system, we observed voltage spikes exceeding ±400 volts at pin 2 (positive input) of the MCCU. These levels greatly exceed the maximum ratings for the control transistor's base-emitter breakdown voltage (BV_{EBR}). The transients generated by the annunciator relay, as well as other transients as high as ±80 volts that can be present on the +28 volt power source, create stress levels that can result in transistor breakdown.

The findings of the circuit analysis, in conjunction with laboratory and field measurements, show that transient protection is necessary for both the input terminals and the +28 volt source.

In addition to the transient problem, evidence of damage to the reed relay contacts was noted in a number of the units examined. Maintenance personnel reported that replacement of the lamps in the Master Caution Indicator resulted in +28 volt supply shorts. This caused excessive current through the MCCU relays. In some instances, the relay contacts fused; in others, the reeds were overheated and would not function properly. Greater care in the replacement of lamps can, of course, alleviate this problem. An alternative approach to eliminating this relay damage is redesign of the MCCU. It could be modified to eliminate the reed relays and provide a short-circuit tolerance for the MCCU lamp load. Such a modification could be implemented in any new MCCU procurements and incorporated in the fleet during MCCU attrition.

3.5 TRANSISTOR FAILURE ANALYSIS

All transistors in the MCCUs received for this contract effort were removed and tested with the Tektronix Type 575 Transistor Curve Tracer. Failed transistors were opened for examination under a microscope.

Initial tests with the transistor curve tracer involved the following transistors:

- 10 each 2N3063 (negative channel); all tested "good".
- 9 each 2N719 (positive channel); one tested "good", eight had failed.

Detailed analyses of the eight failed 2N719 transistors with the transistor tester, followed by examination under the microscope, revealed the following:

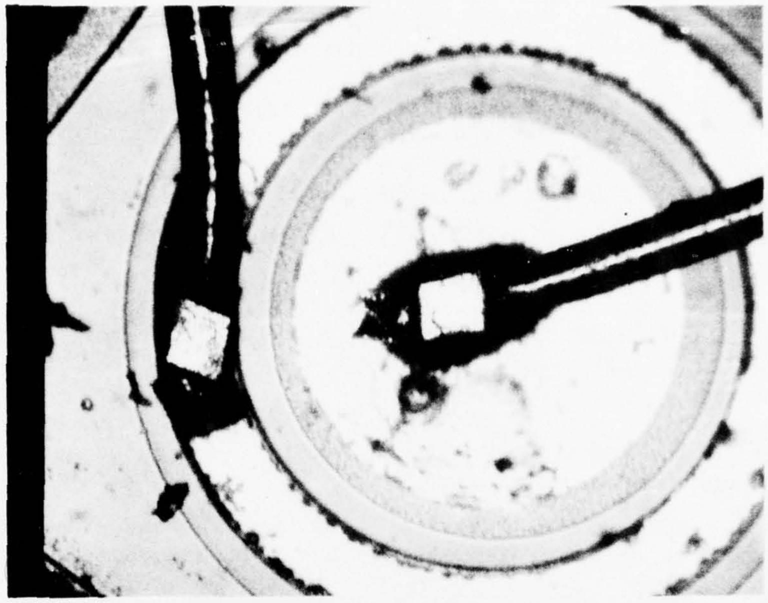
- One -- all elements shorted; evidence of excessive temperature, semiconductor material melted
- Three -- open emitter; emitter lead burned open, evidence of pinpoint temperature extremes on the emitter contact area
- Three -- collector-emitter leakage; evidence of pinpoint temperature extremes on emitter contact area
- One -- collector-emitter and collector-base leakage; evidence of temperature extremes on emitter contact and collector-base areas

The transistor examination revealed evidence of a failure mode that consisted of concentrated temperature extremes in the emitter contact area. The photographs of Figure 3-6 show the typical failure mechanism seen in the transistors examined.

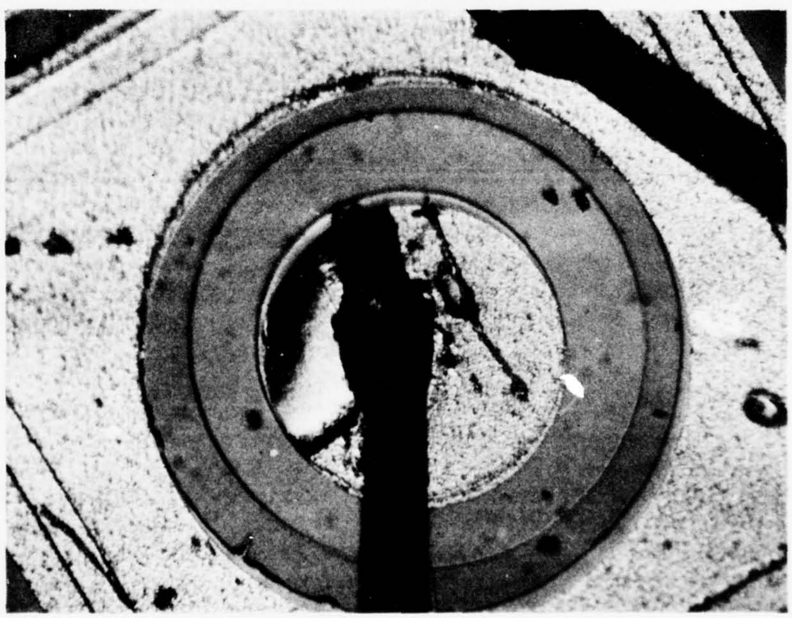
Examination of the failed transistors also revealed significant differences in physical construction and semiconductor geometry from manufacturer to manufacturer. Three different structural designs were found in the eight failed transistors examined, as shown in Figure 3-6. Although this effort did not permit detailed evaluation of the influence of these differences, it is believed that such differences in geometry produce significant variations in performance parameters.

We conducted a laboratory test to identify the levels required to duplicate the observed transistor failure characteristic. The tests used a common emitter circuit, a 3000-ohm collector load resistor with 80-volt collector supply voltage, and a base signal of 1.0-microsecond pulse width at a pulse-recurrence frequency of 2.2 milliseconds (455 Hz) and with an amplitude variable from zero to -28 volts. The transistor failed immediately when the base signal pulse amplitude was increased to about -15 volts peak level. Subsequent measurement indicated that the transistor failed with a collector-emitter short. Examination of the semiconductor revealed the characteristic hot spot on the emitter surface.

We reviewed available transistor specifications, including those for transistors qualified for listing in military standards, to identify possible



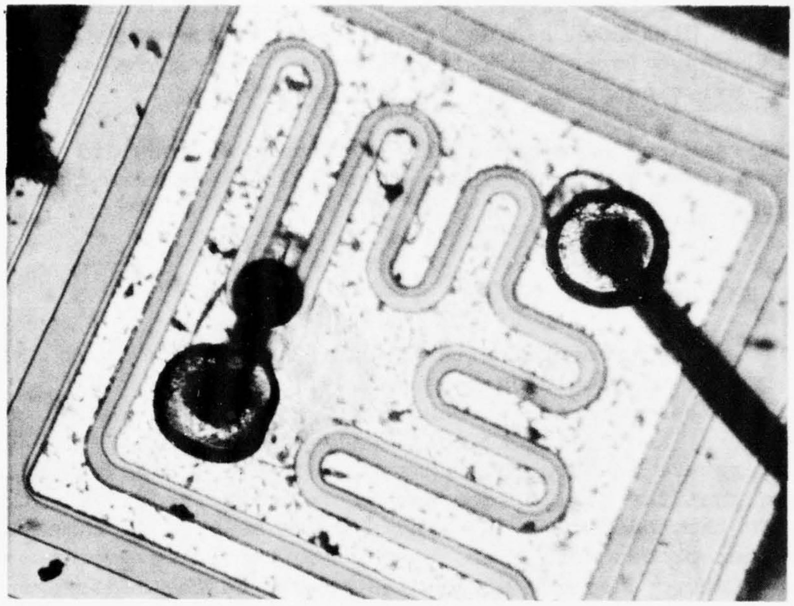
(a) Hot spot shown just below emitter terminal



(b) Melted area to left of emitter terminal

(continued)

Figure 3-6. DIFFERENCES IN 2N719 STRUCTURAL DESIGN



(c) Emitter terminal burned off near semiconductor connection; hot spot shown just above the emitter terminal

Figure 3-6. (continued)

alternative devices for use in the MCCU. We were hopeful of finding transistors with a greater safety margin that would further reduce susceptibility to transient damage. Contaminants had been observed in some commercial units, and we believed that the inspection requirements for military type transistors might reduce the likelihood of contaminants in production units.

The selection of transistors from Military Standard 701G that will satisfy form, fit, and function for this application is limited. The transistors identified as possible substitutes were the 2N2906A (PNP) and 2N2221A (NPN). Maximum ratings for the types used in the MCCU are compared with those of available MIL-Specification types in Table 3-1. The ratings

Table 3-1. TRANSISTOR SPECIFICATIONS

Device Type Number	Device Polarity	Power (mW)	IC (mA)	BV_{CBO} (volts)	BV_{CEO} (volts)	BV_{EBO} (volts)	hFE	Case Style
2N719	NPN	400	1000	120	60	7	20 - 60	TO 18
2N2221A*	NPN	500	800	75	50	6	40 - 120	TO 18
2N3063	PNP	400	100	90	80	40	50	TO 46
2N2906A*	PNP	400	600	60	60	5	40 - 120	TO 18

*MIL-Specification devices.

are for operation in free air at 25°C. Note that the military specification types have lower breakdown ratings than the types currently in use and would not necessarily have lower contaminant levels. *Therefore, we do not recommend* replacing the existing types with the military types.

Detailed research of commercially available devices did not identify any transistors that would provide a significant improvement in breakdown characteristics.

3.6 THERMAL MEASUREMENTS

The MCCU was instrumented with thermistor probes so that component operating temperatures could be measured. The components initially selected for operating temperature measurement were Q1-2N719, Q2-2N3063, R6 and R7 240-ohm resistors, and K1 and K2 reed relays (see Figure 2-3). Preliminary surface-termperature measurements comparing Q1 and Q2, R6 and R7, and K1 and K2 showed that the similar components exhibited nearly identical temperatures. On this basis, Q1, R6, and K2 were selected for measurement. Three thermistor probes were then attached to the selected components in the unit, and interconnecting wiring was routed to the measurement bridge through the opening created by removing connector pin 7.

This configuration permitted operation of the MCCU in its normal housing. The unit was operated in the environmental chamber with the laboratory mock-up as shown in Figure 3-3 (Section 3.3). The environmental chamber was operated for five hours each at 25°C and at 85°C to assure thermal stabilization of all components.

The unit was operated with both channels activated and the caution light's dim mode selected. The dim mode is the worst-case condition for temperature rise within the unit because R6 and R7, the 240-ohm parallel resistors used to reduce caution lamp voltage, are in the circuit. The lamp load consisted of eight type-327 bulbs and duplicated the load of the two master caution lights in the C-141A aircraft.

Figure 3-7 shows the temperatures recorded on the case of transistor Q1-2N719, on the body of 240-ohm resistor R6, and on the side of the reed relay K2. The highest temperatures were recorded on the parallel dimming resistor, R6.

The primary purpose of the thermal measurements was to identify possible stress levels on transistor Q1. A review of available data on thermal characteristics of transistors used in the MCCU revealed the following:

- 2N719 -- 1.5 watts is specified as total device dissipation at or below 25°C case temperature. Derating is to be linearly applied up to 175°C case temperature at the rate of 10.0 mW/°C. The transistor is also specified for 0.4-watt dissipation in 25°C free air, derated at the rate of 2.6 mW/°C to 175°C.

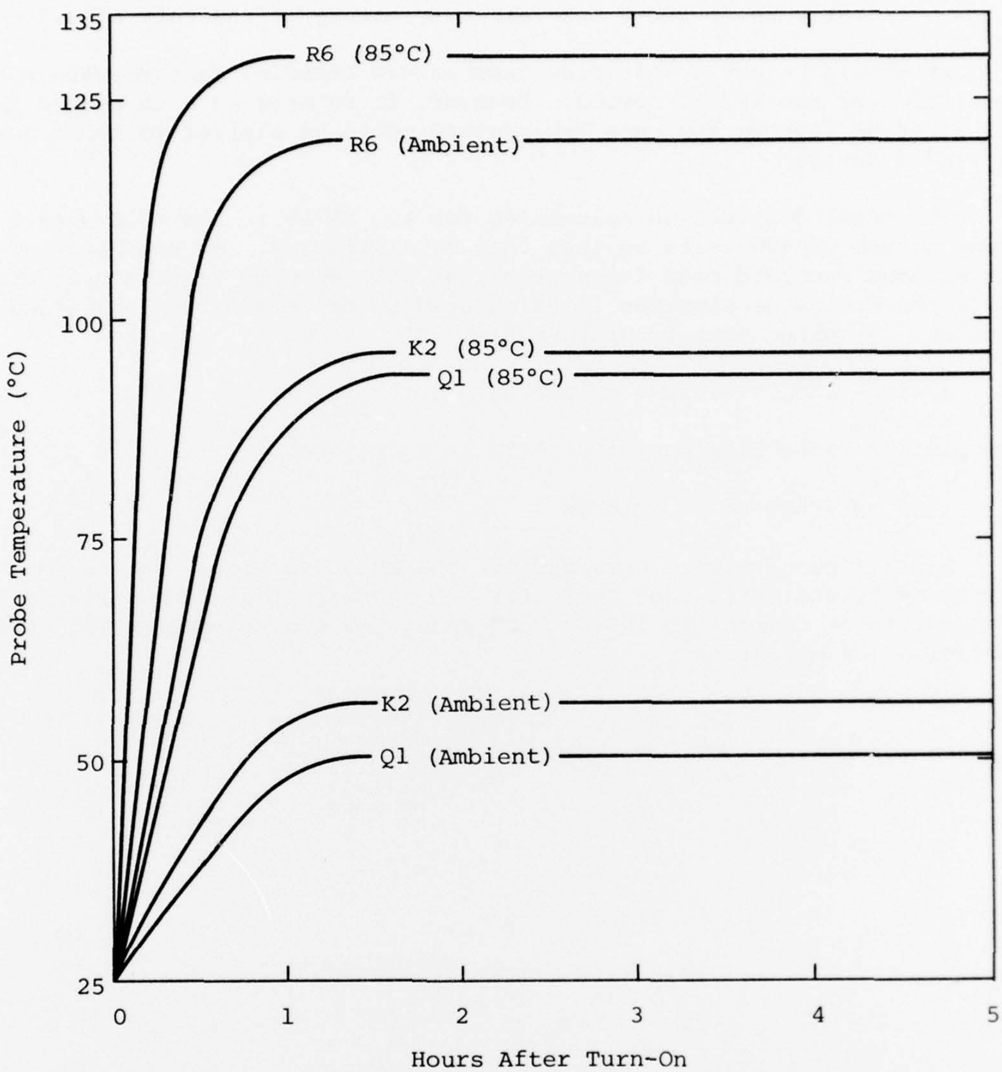


Figure 3-7. THERMAL MEASUREMENTS

- 2N3063 -- 0.4 watt is specified as total device dissipation at or below 25°C free air temperature. Derating is to be applied linearly up to 200°C free air temperature at the rate of 2.3 mW/°C.

It should be noted that case-temperature derating factors were not specified for the 2N3063 device. However, it appears safe to assume that the derating factors for case temperature would be similar to those for the 2N719 device.

The total dissipation calculated for the 2N719 in the MCCU with a power source of +28 volts is less than 12 milliwatts. On the basis of the maximum recorded case temperature (at 85°C chamber temperature) of 94°C, the device dissipation is calculated to be well within specified ratings. Required temperature derating is

$$(94°C - 25°C) \times 10 \text{ mW} = 690 \text{ mW}$$

The maximum rated dissipation at 94°C is therefore

$$1500 \text{ mW} - 690 \text{ mW} = 810 \text{ mW}$$

Similar results were obtained for the 2N3063 device. The thermal measurements indicated that there were no thermal problems associated with transistors or components in the MCCU under the most severe anticipated conditions of operation.

CHAPTER FOUR

MODIFICATION AND FLIGHT-TEST DATA

4.1 MODIFICATION DATA

The modification to the MCCU developed in this study consists of incorporating three transient-protection devices at the input and power terminals.

All data necessary for incorporating this modification are provided in the Appendix, which includes instructions and schematics. Full-size copies and reproducible copies of the drawings accompany this report. Incorporation of this modification will require approximately 0.5 man-hour per unit.

It will not be necessary to change technical manuals with regard to performance or bench testing. The manuals should be reviewed, however, to include additions to the IPB pictures and part listings and to assure that circuit-performance descriptions and schematics are updated.

No significant weight changes result from this modification (an increase of approximately 6 grams).

4.2 FLIGHT-TEST DATA

Modified MCCUs are being flight-tested at McGuire Air Force Base by the 438th Military Airlift Wing. The modified units were installed by the Air Force technicians whenever an original MCCU failed in the C-141A aircraft and a modified unit was available.

Delays in receipt of units, as well as poor condition of the units, made it impossible to deliver the ten modified units for flight test by 15 June 1976 as originally planned. The modified units were delivered to McGuire Air Force Base as follows:

- 10 June 1976 -- 2 units, S/N's 3042 and 3062
- 17 June 1976 -- 3 units, S/N's 2780, 2870, and 3844
- 15 July 1976 -- 5 units, S/N's 2740, 2588, 2858, 2821, and 3042

The first five units delivered contained transient-protection diodes only across the signal input terminals on the basis of the initial aircraft measurements. The last five units also included transient protection for the +28 volt input lines, incorporated as a result of the additional measurements at McGuire Air Force Base.

Unit S/N 3042 was removed from aircraft 8076 on 6 July 1976 after 83 flight hours because the positive channel in the unit was continuously activated whenever power was applied. The failure mode was identified as collector-emitter leakage in transistor Q1 (2N719). Examination of the defective transistor under a microscope revealed fabrication defects and contamination in the semiconductor element. There was no evidence of overheating. This transistor had been procured commercially and installed by ARINC Research. Unit S/N 3042 was repaired, modified with the additional transient-protection diode on the +28 volt line, and returned to the flight-test program.

Unit S/N 2870 was removed from aircraft 7947 on 8 July 1976 after 44.6 flight hours because neither channel would activate the master caution light. The failure mode was identified as an "open" +28 volt lamp circuit. S/N 2870 was one of the scrapped units initially provided by the Air Force. It had previously undergone extensive repair attempts by the Air Force, including relay replacement, which damaged the printed-circuit-board lands. The cause of the failure was found to be a crack in the land connecting the relay contact circuits. The damaged land was not evident in the test and inspection at ARINC Research prior to delivery because it was concealed by component placement. This unit was removed from the flight-test program because of the potential for further failure.

Each unit delivered for the flight-test program was identified by a decal designating it as a modified unit. When the modified units were installed, appropriate entries were made in the aircraft records by the 438th Military Airlift Wing technicians. Table 4-1 is the data record for MCCUs employed in the flight-test program.

As of the end of July 1976 the modified MCCUs in the flight-test program have accumulated 634 hours' flight time. Unit serial number 2821 has not been installed. Flight testing will continue, and additional data will be available from the 438th Military Airlift Wing, McGuire Air Force Base.

Table 4-1. FLIGHT-TEST DATA				
Test Unit Serial Number	Date Installed	Aircraft Serial Number	Aircraft Hours at Installation	Comments
3042*	6/14	8076	14941.0	Removed 7/6 at 83.0 hours
3062	6/16	0149	11707.6	109.4 hours**
2780	6/22	0010	14710.3	115.7 hours
2870	6/21	7947	15088.2	Removed 7/8 after 44.6 hours
3844	6/21	8083	16555.7	115.3 hours
2740	7/16	0626	18219.0	50.0 hours
2588	7/16	0622	17943.0	24.0 hours
2858	7/19	0021	16080.0	9.0 hours
2821	--	--	--	Not installed
3042*	7/19	0019	13164.0	83.0 hours

*Repaired and returned to McGuire Air Force Base for further flight test.

**All accumulated hours in "Comments" column are for the period ending 30 July 1976, except as noted.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The predominant failures noted in the Master Caution Control Unit are the 2N719 transistor and, to a less significant degree, the 2N3063. It appears that the lower failure rate of the 2N3063 is related to this transistor's higher breakdown ratings.

The most severe transients were observed during the application and removal of ground power -- actions that are normally associated with maintenance of other systems on the aircraft. Transients were generated when annunciators were energized and not cleared prior to removal of ground power.

5.2 RECOMMENDATIONS

The transistors used in the MCCU design are commercial units. Considerable latitude is permitted within type number with regard to physical configuration, parametric variation, and quality control. Inspection of many of the failed units revealed evidence of contaminants and other quality defects. The use of military transistors in the application does not seem possible. Consideration should be given, however, to screening the commercial items to obtain better quality, particularly with regard to allowable leakage current.

Since the most serious transients observed are associated with the release of the energy stored in each of the annunciator relays, and their cumulative effect can result in damage to components in the MCCU, two possible solutions were considered. One solution is to install transient-suppression diodes across all 50 annunciator relay coils. This approach would be expensive, but it would eliminate a substantial part of the problem at its source.

The recommended procedure is considerably less expensive and requires the installation of transient-suppression diodes on the two signal leads and the 28 volt lead in the MCCU as shown in the Appendix to this report. This "brute force" approach will limit the transients introduced into the unit and thereby reduce the stresses on the individual components rather than prevent the transients from occurring.

APPENDIX

MODIFICATION INSTRUCTIONS
FOR THE C-141A MASTER CAUTION CONTROL UNIT

1. PURPOSE OF MODIFICATION

The purpose of this modification is to improve the reliability of the C-141A Master Caution Control Unit by incorporating transient-protection devices.

2. *REFERENCES*

ARINC Research Publication 1904-01-1-1524

ARINC Research Drawings C001008 and C001009

3. UNIT IDENTIFICATION

Master Caution Control, Manufacturer Code 96182, P/N 861-100-3

NSN: 6340-00-918-8427

4. LOGISTICS DATA

(1) The following materials are required:

Item	Quantity	Part Number	Nomenclature
1	3	1N5555	Diode
2	2 inch	.250 IDX .62 LG ALPHA FIT 221	Insulation, Shrinkable

(2) No parts are removed.

5. PREPARATION

Before this modification is performed, the unit shall be verified as operational.

6. DETAILED INSTRUCTIONS

Step 1. Remove four (4) screws holding connector to unit.

Step 2. Carefully pull on connector and slide printed circuit board out of housing.

Step 3. Using a No. 64 drill (0.036), locate and drill hole in accordance with Detail A in Drawing C001008.

Step 4. Using solder sucker, remove solder from green wire terminal to expose existing hole.

Step 5. Cut three (3) lengths of 0.0250" ID heat-shrinkable insulation to 0.62" long.

Step 6. Bend cathode lead around the end along the side of the body on two (2) 1N5555 diodes. (Refer to CR4 and CR5, Drawing C001008). Center heat-shrinkable insulation (Step 5) over body of diodes and shrink with heat gun. Trim the lead to a length of 0.375" from diode body.

Step 7. Center heat-shrinkable insulation over remaining diode (CR6, Drawing C001008) and shrink with heat gun. Bend both leads 90° at a point 0.250" from the body ends of the diode.

Step 8. Install diode CR6 on resistor side of board as shown in Drawing C001008 (the cathode end to the green lead connection). Trim lead ends and solder.

Step 9. Place diodes CR4 and CR5 as shown in Drawing C001008 (observe polarity as shown). Solder in place and press each diode as close as possible to printed circuit board and relay. Ensure that the leads on Q1 and Q2 are trimmed as close as possible to the printed circuit board.

Step 10. Clean flux residue from soldered areas.

Step 11. Reinstall unit in case and verify operational performance in the shop test set.

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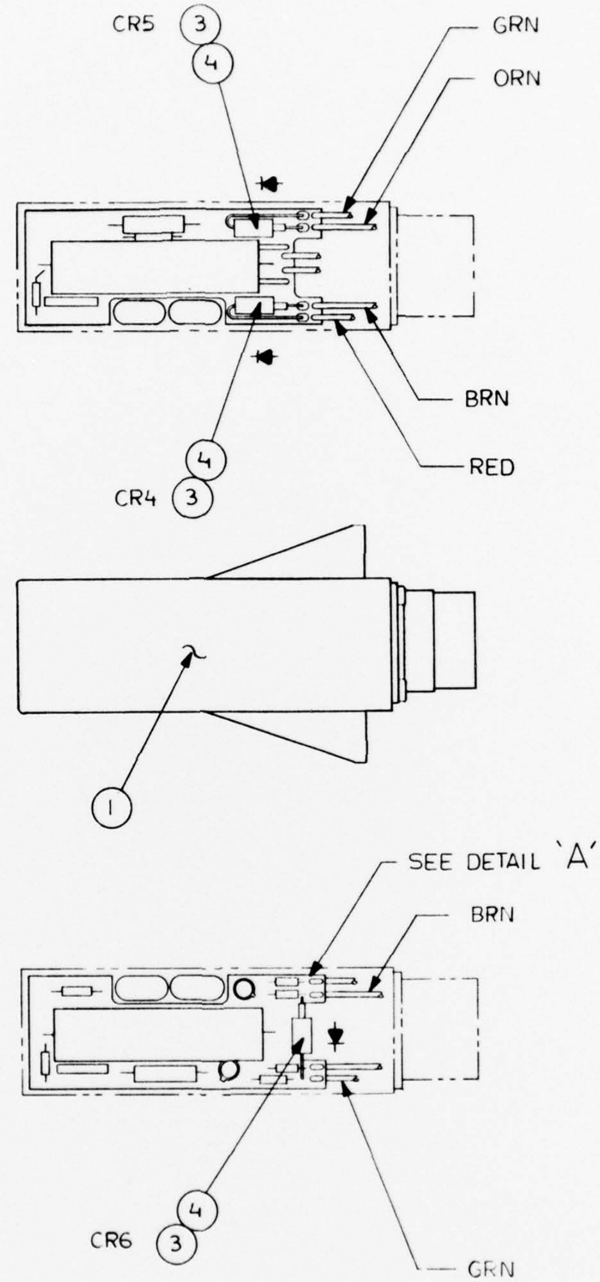

C

.036 +.004 −.002 DIA

NOTE:

1. SOLDER IN
USING ITE

B

	A/R	SOLDER
	3	INSULATION, SHR
	3	DIODE CR
	REF	SCHEMATIC DIAG
	REF	MASTER CAUTION
	QTY. REQ.	DESCRIPTIO

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCES ON:
FRACT. ± — DECIMALS .XX ± .03 .XXX ± .010 ANGLES ± —

MATERIAL

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REVISIONS

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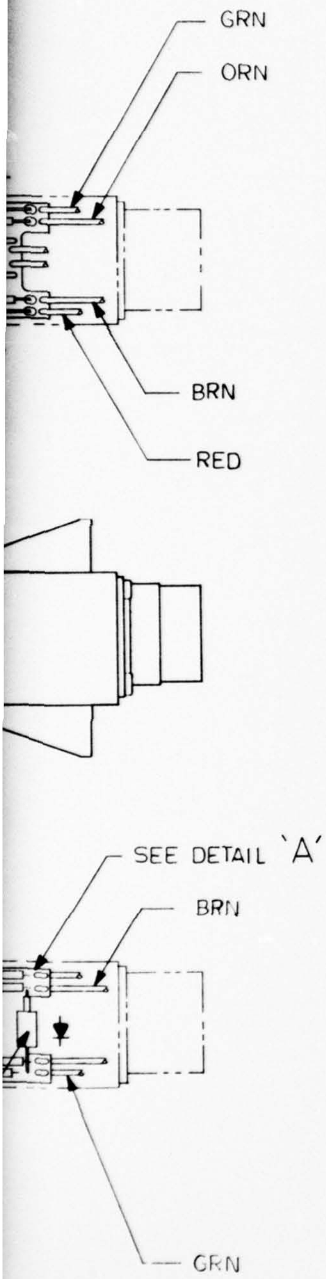

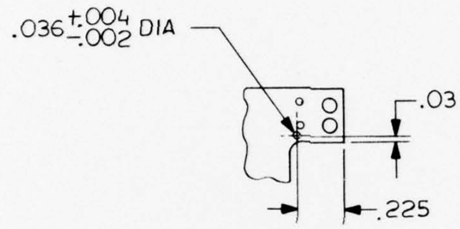

DETAIL 'A'
SCALE 2/1

NOTE:

1. SOLDER IN ACCORDANCE WITH MIL-STD-454, REQUIREMENT 5, USING ITEM 5.

LIST OF MATERIALS

QTY. REQ.	DESCRIPTION	PART NO.	MATERIAL	SPECIFICATION	ZONE	ITEM
A/R	SOLDER	QQ-S-571, SN60				5
3	INSULATION, SHRINKABLE	.250 ID X .62 LG		MIL-I-23053, CL3		4
3	DIODE CR4 - CR6	IN5555		MIL-S-19500/434		3
REF	SCHEMATIC DIAGRAM	C001009				2
REF	MASTER CAUTION CONTROL	861-100-3	MASTER SPECIALTIES CODE IDENT 96182			1

ITEM	QTY.	NEXT ASSY	USED ON

APPLICATION

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FRACT. ± — DECIMALS .XX ± .03 .XXX ± .010 ANGLES ± —
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WORK ORDER NO. 1504-01
CONTRACT NO. F09603 76-A 3231-SA02

ARINC RESEARCH CORPORATION

TITLE MASTER CAUTION CONTROL MODIFIED

SIZE C DWG. NO. C001008
SCALE 1/1 SHEET 1 OF 1

C001008

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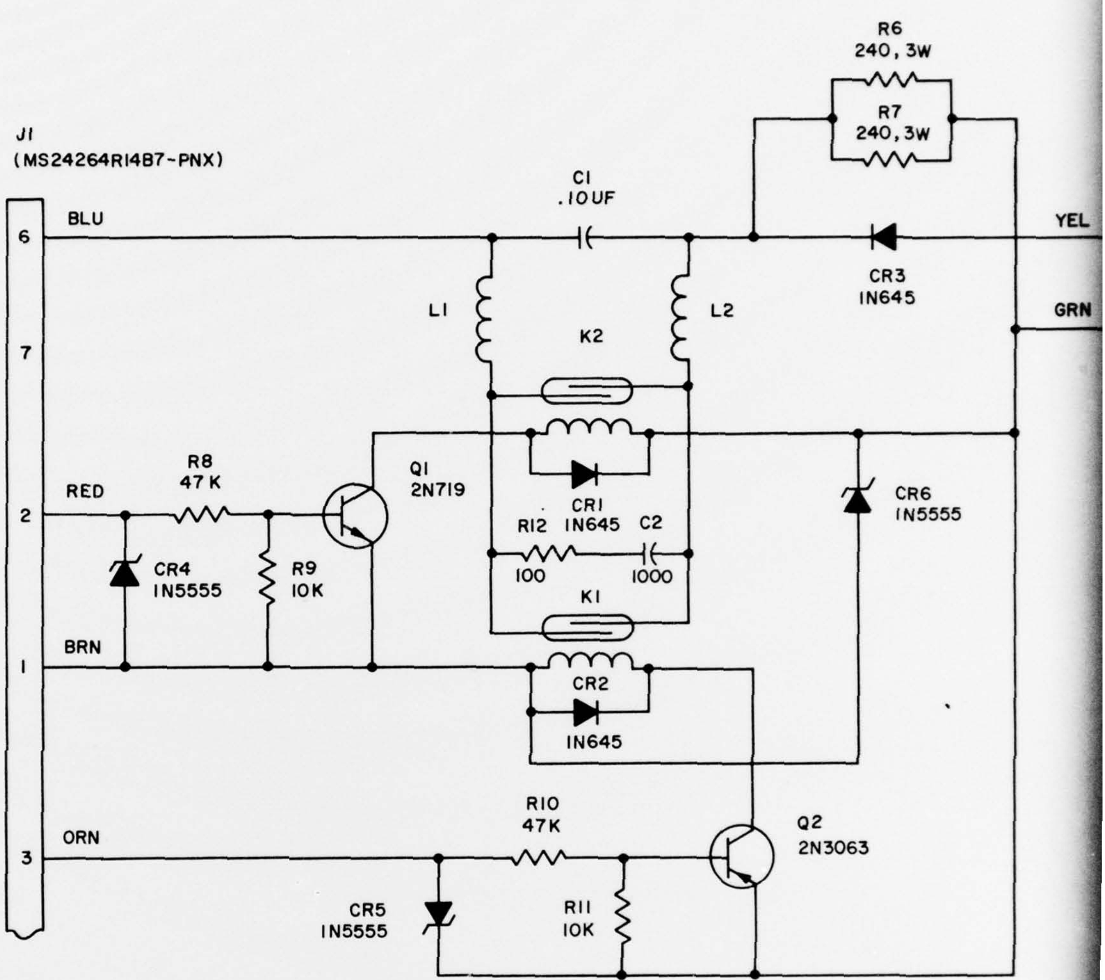

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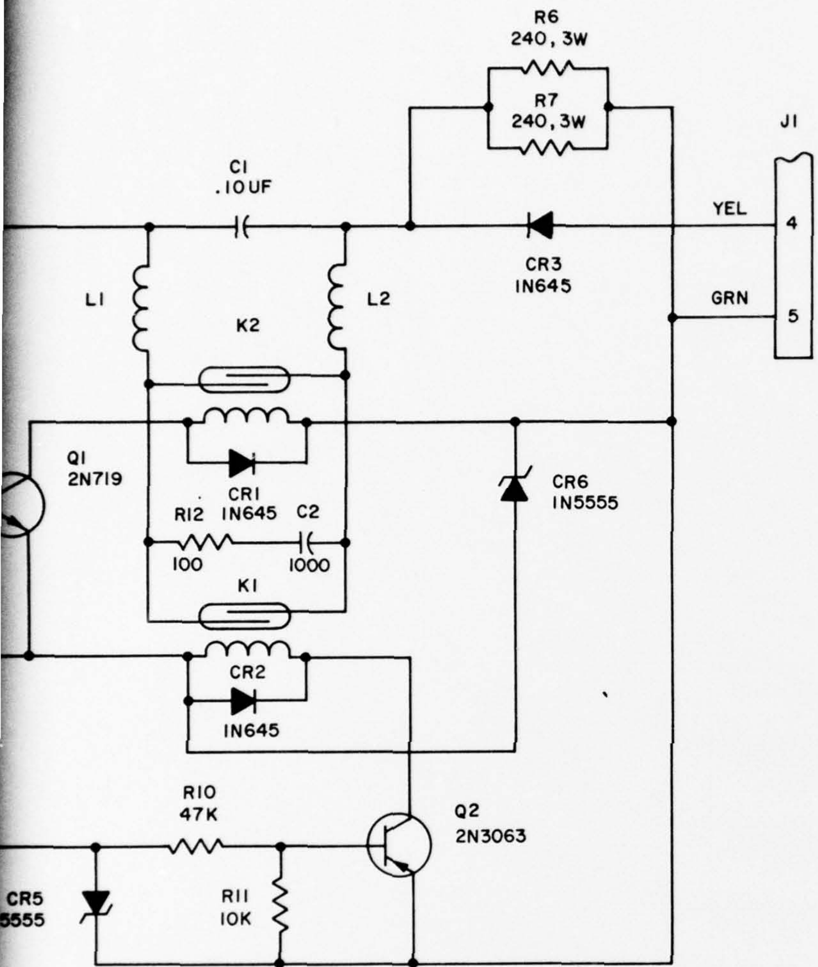

C

NOTES:

1. UNLESS OTHERWISE SPECIFIED:
   ALL RESISTOR VALUES ARE IN OHMS, 1/4W
   ALL CAPACITOR VALUES ARE IN PICO-FARADS
2. RELAYS K1 AND K2 ARE P/N 964-15613-000H(LP)

C001009

QTY. REQ.		DESCRIPTION	PART NO.	MATERIAL	SPECIFICATION	ZONE	ITEM

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	
TOLERANCES ON: FRACT. ± — DECIMALS .XX ± — .XXX ± — ANGLES ± —	
MATERIAL	
TREATMENT	
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CHKD.		
APPD.		
WORK ORDER NO.	1904-01	
CONTRACT NO.	F09603-76-A-3231-SA02	

ARINC RESEARCH CORPORATION

TITLE SCHEMATIC DIAGRAM MASTER CAUTION CONTROL

SIZE	DWG. NO.
C	C001009

SCALE NONE | SHEET 1 OF 1

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APPLICATION

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This report presents the results of a program to improve the reliability of the C-141A Master Caution Control Unit, NSN 6340-00-918-8427. The program was performed by ARINC Research Corporation under contract with the PRAM Program Office, San Antonio Air Logistics Center, Kelly Air Force Base, Texas, during the period 17 March 1976 through 21 July 1976.

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